Contributions

Katherine K. Grooms*

Does Water Quality Improve When a Safe Drinking Water Act Violation Is Issued? A Study of the Effectiveness of the SDWA in California

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Abstract: The Safe Drinking Water Act addresses harmful contaminants in drinking water by providing states the authority to monitor public water systems, notify the public of exceedances above allowable levels, and cite persistent violators. Violating water systems are subject to intense regulatory and public scrutiny. The response of contaminant levels to violation status has not been explored empirically. This paper addresses this relationship through an event study using data on arsenic and nitrate levels in California. I find that violation status has a significant positive effect on nitrate levels post-violation, but no effect on arsenic levels. I also examine the effect of the 2006 arsenic Maximum Contaminant Level revision, finding a discontinuity in contaminant levels at revision. These results suggest that while public disclosure may deter systems from violating, once they go into violation the Public Notification Rule is not effective at encouraging a return to compliance.

Keywords: Safe Drinking Water Act, violation response, water quality

1 Introduction

The US government passed two regulations in the 1970s in an effort to combat industrial water pollution and ensure clean drinking water supplies nationwide. The Clean Water Act (CWA) addresses permitting of facilities which discharge pollutants into the nation's waters to mitigate point source or industrial pollution. The Safe Drinking Water Act (SDWA) protects the nation's drinking water by regulating contaminants in the drinking water supply. These two policies

*Corresponding author: Katherine K. Grooms, Department of Economics and Business, Southwestern University, Georgetown, TX 78626, USA, E-mail: groomsk@southwestern.edu

were designed to safeguard both environmental and human health by providing an acceptable level of water quality in lakes and streams and in drinking water. However, the effectiveness of these policies and their ability to achieve the goal of improving water quality has been questioned. Failures of enforcement of the CWA have been well documented anecdotally in a series of articles in the *New York Times*, in government reports completed by the Government Accountability Office, and in the empirical law and economics literature (Duhigg 2009a; U.S. General Accounting Office 1996; U.S. Government Accountability Office 2007, 2009; Sigman 2005; Flatt 1997; Grooms 2014).

Unlike the CWA, the SDWA regulates drinking water contaminant levels directly. Thus, understanding the effectiveness of this policy is crucial as lax enforcement or compliance may have a detrimental effect on human health. Water systems must comply with Maximum Contaminant Level (MCL) standards for various contaminants. Failure to comply results in a violation, often required public notification, and additional regulatory scrutiny. Existing work has not addressed whether the scrutiny triggered by being found in violation of an MCL is a deterrent against remaining in violation, or rather, whether water quality improves after a violation is detected. This paper contributes empirical evidence on how contaminant levels respond to violation status.

The main mechanism for encouraging compliance after violation is required public notification and increased monitoring. Water system managers must weigh the cost of compliance against the expected cost of additional scrutiny. If the goal of the policy is to avoid contaminants in excess of agreed-upon health thresholds, effective enforcement would induce a higher expected cost to water systems of violating than the expected cost of compliance. If systems do violate, the expected high cost of continued noncompliance should induce systems to return to compliance quickly.

Greenstone (2004) addresses a similar question, examining the effect of non-attainment designation under the Clean Air Act on emissions. Nonattainment designation imposes an additional regulatory burden on counties and thus has some similarities to violation status under the SDWA. Using a similar empirical methodology to this paper, Hanna and Oliva (2004) examine the effect of inspections on plant-level air emissions. The relationship between repetitive system-level official violations and system-level contaminant levels under the SDWA has not been explored empirically, although anecdotal evidence suggests that SDWA violations are persistent and that violating water systems are not fined or penalized (Duhigg 2009b). A recent article in the *New York Times* points to issues and inefficiencies in SDWA funding distribution to address and clean up contaminated water systems, naming the state of California specifically as the worst offender (Barringer 2013).

Existing literature on the SDWA has addressed avoidance behavior by residents when water systems are in violation of MCL standards (Graff Zivin, Neidell, and Schlenker 2011), studied strategic noncompliance by water systems exploiting sampling rules (Bennear, Jessoe, and Olmstead 2009), and examined the effect of laws that require violation notification to customers on violation rates (Bennear and Olmstead 2008). Other literature has addressed the health effects of water pollution by studying the effect of exposure in utero to polluted water, measured by water system violations, on fetal health in New Jersey (Currie et al. 2013).

This paper combines data on drinking water contaminant sampling across the state of California between 2000 and 2012 with data on official violations to provide empirical evidence on the reaction of water systems to violations. California water systems serve a population of around 33 million people through close to 8,000 public water systems (PWSs) across 58 counties. California provides a large and diverse sample for study across many counties and water systems, while still remaining under one regulatory authority. Because the SDWA is regulated primarily at the state level, exploiting within state variation is appropriate.¹ This study focuses on the effect of violations on arsenic and nitrate levels in water systems across California. These two contaminants are harmful to human health at very low doses and they are widely sampled. Additionally, while the standard for nitrate was set in 1977 and has not since been revised, the standard for arsenic was revised in 2006, allowing me to explore the effect of a change in the standard on pollution levels.

I use an event study to address the effect of violation status on contaminant levels, using up to seven quarters before and after a violation. I find that water systems with nitrate violations experience an increase in contaminant levels post-violation, but violation status has no effect on arsenic concentrations. As both arsenic and nitrate are prevalent across water systems in California, these results are somewhat troubling. Additionally, I find that violation status one quarter in the past is predictive of violation status today, suggesting that violations are persistent over time at certain systems. I also undertake a study of the effect of the revision of the arsenic standard on pollution levels. I find a discontinuity at the revision for the small sample of systems sampled over the entire period, with contaminant levels lower after revision. Public disclosure and scrutiny is the primary threat associated with violating the SDWA and these results together suggest that public disclosure is a deterrent to violating, but

¹ MCLs for pollutants vary in stringency from state to state. The Federal EPA sets maximum standards for all pollutants but states have a fair amount of discretion in tightening these standards.

once in violation, systems are not pressured to remedy their noncompliance to avoid continued scrutiny.

The paper is organized as follows: Section 2 provides background on the structure and enforcement of the SDWA. Section 3 provides a conceptual framework. Section 4 discusses the data used for the analysis and my empirical strategy. Section 5 provides results. Section 6 concludes.

2 Enforcement under the SDWA

The SDWA was passed in 1974 to address the public health threat of waterborne contaminants. Under the SDWA, the Environmental Protection Agency (EPA) sets standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water.² The EPA sets MCLs, which dictate the threshold below which the health risk is nonexistent or minimal. To determine which contaminants require an MCL, the EPA examines peer-reviewed scientific reports, including data on how often the contaminant is present, how exposure would occur, and the health effects as a result of exposure. States assume the primary responsibility for monitoring and enforcing the provisions of the SDWA. In California, the California Department of Public Health (CDPH) has primacy to enforce the SDWA.

PWSs are the primary focus of the SDWA. A PWS is defined as a water system that provides water for human consumption and has at least 15 or more service connections or regularly services at least 25 individuals daily at least 60 days out of the year.³ A subset of PWSs are community water systems (CWS), which is a slightly more restrictive definition of PWSs as the connections and individuals are required to be yearlong residents. California has around 8,000 PWSs, around 3,000 of which are CWSs. PWSs must be permitted under the SDWA for provision of safe drinking water to residents. Water systems that serve under 25 individuals are not regulated under the SDWA. These water systems may be investor-owned or public. Investor-owned water systems are strictly regulated by the California Public Utilities Commission (CPUC). There are only 113 investor-owned water utilities in the state of California regulated by the CPUC.⁴

² Source: [water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm](https://www.water.epa.gov/lawsregs/rulesregs/sdwa/index.cfm).

³ Section 116275 of the California Safe Drinking Water Act (Part 12, Chapter 4 of the California Health and Safety Code).

⁴ CPUC Division of Water and Audits.

Permitted PWSs are then subject to monitoring and enforcement under the SDWA, specifically from the CDPH. Monitoring takes two forms for these systems. The CDPH dispatches inspectors to detect and remedy treatment issues to help water systems remain in compliance. However, the minimum inspection rule for systems ranges from once a year to once every 3 years. There is no documentation on how inspections are carried out and how often systems are actually inspected. While on-site inspections are important for monitoring system activity, the most crucial monitoring function of the CDPH is to require that systems regularly test for contaminants and report these results.⁵ This sampling activity forms the backbone of monitoring by CDPH as these samples are used to decide if a system is in violation of the MCL for a given contaminant and to alert the public to avoid potential health problems associated with overages in any waterborne contaminants.

Systems can be found in violation of the SDWA for several reasons. The least crucial involves violating monitoring and reporting requirements. These violations emerge when systems fail to monitor and sample for contaminants on a prescribed schedule as discussed above or when systems fail to report the results of monitoring in a timely manner. A system would be found in violation for each individual chemical they failed to monitor or report.

The most crucial violations are MCL violations, or violations of the human health standard. These violations are of the greatest concern for human health and trigger public notification and more intense follow-up monitoring. Public notification is one of the key provisions of the SDWA to alert consumers of drinking water violations and instruct them on how to address the specific violation to avoid health risks. The rules regarding public notification are defined by the Public Notification Rule. This rule was passed to define the timing of notice, how notice is distributed, and the required information contained in the notice. The urgency of notice is classified by Tiers.⁶ Tier 2 notifications are required for all violations of an MCL (unless a Tier 1 notification is required). Tier 2 notifications are required to take place as soon as practical but within 30 days of the violation. The water system must continue notification every 3 months after the initial notification if the violation is not resolved. Tier 1 notifications are required for violations that pose a very immediate human health risk, including violations of fecal coliform and nitrate MCL violations. These notifications must be given as soon as possible but within 24 h of violation detection. All notifications require

⁵ System sampling frequency varies across contaminants but is usually at least quarterly.

⁶ Tier 3 notification is required within 12 months of violation and repeated annually until the violation is resolved. Violations of monitoring or testing procedures fall under Tier 3 notifications. These are violations that do not pose an immediate threat to public health.

detail on the violation, contaminants of concern, health effects from exposure to these contaminants, population specifically at risk, and particularly vulnerable subpopulations (infants, etc.), whether consumers should seek alternative water supplies, when to seek medical help, how the PWS will correct the violation, and how quickly they will return to compliance. Notices must be sent to the CDPH within 10 days of consumer notification and must be kept on file for 3 years.⁷

If violating systems do not return to compliance, the department can require the PWS to develop a plan of compliance, including a plan to provide an alternate source of water, possibly abandon the contaminated source, conduct additional monitoring to identify and address the cause of contamination, install new facilities for treatment, or issue boil water notices. Finally, the department can revoke permits and issue civil penalties of up to \$25,000 per day for each day of violation. However, while CDPH has the power to issue fines, fines remain at a very low level relative to the number of MCL violations. In 2005, 2006, and 2007 there were 921, 980, and 804 MCL violations, respectively, but over 2005–2006 and 2006–2007 total fines were only \$25,630 and \$10,860, respectively.⁸

Given the public notification and scrutiny triggered by violation status, and the relatively small nature of fines, violation status is one of the key functions of the SDWA. The continued public and regulatory scrutiny through public notification and follow-up monitoring, and the potential need to develop a plan of compliance should encourage systems to return to compliance quickly. There is empirical evidence that consumers both notice and pay attention to the required public notification. Graff Zivin, Neidell, and Schlenker (2011) found that MCL violations cause an increase in bottled water consumption. To identify this effect, Graff Zivin, Neidell, and Schlenker (2011) assume that all MCL violations trigger public notification, as per the Public Notification Rule.⁹

Systems also take public scrutiny seriously. Bennear and Olmstead (2008) address the effect of the 1996 amendment to the SDWA requiring systems to file annual consumer confidence reports (CCRs) on violations. CCRs are distributed annually by water systems to their consumers and are required to contain information on all violations, including monitoring and reporting violations and MCL violations, and the level of contaminants, even if not above the limit. They find that this mandatory disclosure of information to the public decreased

7 Information on the Public Notification Rule is from <http://water.epa.gov/lawsregs/rulesregs/sdwa/publicnotification/upload/pnrulequickrefguide.pdf>.

8 Source: <http://www.sor.govoffice3.com/vertical/Sites/%7B3BDD1595-792B-4D20-8D44-626EF05648C7%7D/uploads/%7BEBDEB6F2-DBD7-4728-B2D3-C627BE99185A%7D.PDF>.

9 From Graff Zivin, Neidell, and Schlenker (2011): “We do not have data on the exact details of the notification provided by districts.”

violations. Most importantly, enforcement and fines did not change over the same period, thus the deterrence can be attributed to the new provision for public scrutiny. As Benneer and Olmstead (2008) demonstrate, water systems wish to avoid public and regulatory scrutiny. This may have the effect of deterring violations, as they found, but it also gives systems that violate a large incentive to return to compliance, as violations trigger continued scrutiny until the system returns to compliance. This paper addresses the question of whether the increased scrutiny following violation is effective at encouraging systems to return to compliance and decrease contaminant levels. Additionally, through the revision of the MCL standard on arsenic, I can examine the deterrence effect, as systems were suddenly subject to a new rule on what constitutes a violation of the arsenic MCL.

3 Conceptual Framework

Assume a PWSs' goal is to maximize water quality subject to a budget constraint. Their budget is constrained by available funding, either investor-sourced or public and revenue from the population they serve. Both investor-owned and public systems can apply for loan funding through the Drinking Water State Revolving Fund (DWSRF) for planning and design and for construction of new plants.¹⁰

As discussed in Section 2, PWSs respond to consumer oversight by decreasing violations (Benneer and Olmstead 2008).¹¹ In addition to consumer scrutiny, the incentive to maintain water quality is affected by regulation. Water systems have an incentive to comply if they believe that they will face penalties or increased oversight from regulatory authorities. Both of these impose a cost on the system. Compliance is also costly. In any given period, the system must balance compliance costs against expected penalties for noncompliance. For certain contaminants, compliance requires large fixed cost capital investments, such as new treatment plants or technologies.

10 From the DWSRF: "The purpose of the DWSRF is to provide financial assistance for the planning/design and construction of drinking water infrastructure projects that are needed to achieve or maintain compliance with federal and state drinking water statutes and regulations." Accessed at http://www.waterboards.ca.gov/drinking_water/services/funding/documents/srf/dwsrf_faq.pdf.

11 Water systems may respond to consumer scrutiny differently depending on whether they are investor-owned or public. Investor-owned water systems with multiple systems may wish to avoid reputational spillovers. Public systems may be concerned about the effect of poor water quality on property values and tax revenue.

To induce compliance, the expected penalty from either the regulation or public scrutiny must be greater than the cost of compliance. A high cost of compliance also captures an inability to adapt in the short run. The cost of compliance is a function of the contaminant, the level of contamination, and the current treatment technologies. The cost of compliance for a given system is unobserved. If the expected penalty is higher than the cost of compliance, we would expect that water systems would quickly resolve any violations and return to compliance. If the expected penalty is less than the cost of compliance, we would expect to observe high levels of contaminants even after the required public notification and regulatory violation. Once a system is in violation, the expected penalty rises as the violation persists. The cost of compliance may remain flat or rise after violation. The relative magnitude of the cost of compliance to the increased expected penalty determines whether the system returns to compliance quickly. If the system violates because the ability to change treatment technology is constrained in the short run, contaminant levels will not fall following a violation.

4 Data Sources and Empirical Strategy

To examine the response of water quality to SDWA violations, I bring together data on water quality monitoring and reported violations. This section details the sources of data used in the empirical analysis, describes the data, and discusses my empirical strategy.

4.1 Violation Data

The CDPH is required to report drinking water system violations to the US EPA and the public. Each quarter, the CDPH submits water system inventory information, violation incidents, and information on enforcement activities to the US EPA's Safe Drinking Water Information System (SDWIS). The data can be downloaded directly from SDWIS. The dataset includes details on the water system, type of violation, chemicals in violation, and the date of violation. I limit the type of violation to "MCL" violations, or violations where the level of a contaminant is above the acceptable health threshold. These violations trigger the Public Notification Rule discussed above and are thus the most relevant for evaluating the effectiveness of public scrutiny at returning systems to compliance.

4.2 Monitoring Data

The dataset on water system contaminant levels comes from the California Drinking Water Quality Sampling Results Dataset (CDWQS).¹² The dataset covers 1999–2012. It contains daily, quarterly, and yearly measures of arsenic, nitrate, uranium, radium, trichloroethylene (TCE), tetrachloroethylene (PCE), atrazine, and di (2-ethylhexyl) phthalate (DEHP) in public drinking water supplies in CWS. Data are derived from California Office of Drinking Water (ODW) Water Quality Monitoring Database (WQMD, also known as Water Quality Inventory or WQI) and Permits, Inspection, Compliance, Monitoring, and Enforcement (PICME) database. For nitrates, the dataset contains one record for each CWS per quarter and year with average concentrations of nitrates as well as the frequency of sampling, the number of sampling stations, and the date of the last sample. The dataset on arsenic is more disaggregated to the sampling station/sample date level. These data can be aggregated to the quarter/year/water system level to match with the quarter/year/CWS-level violation data.

The quarterly indicators dataset provides the most accurate measures of water quality at the point of entry to the distribution system (the water is tested at many points, including pretreatment). The relevant measure of drinking water quality is when drinking water enters the distribution system, immediately before it is consumed. The CDWQS attempts to construct an average measure of exposure to contaminants across the numerous sampling sites in a water system. Because the CDWQS is an average across the system, points within the water system may have much higher or lower levels of contaminants. While this is a shortcoming of this dataset, the CDWQS dataset still provides the best approximation of the average contaminant composition and exposure across the entire water system while limiting the effect of outlier samples within the water system.

4.3 Contaminants of Interest: Nitrate and Arsenic

While California monitors an array of chemicals under the SDWA, I have limited the analysis to nitrate and arsenic. These chemicals are frequently sampled and both nitrate and arsenic are thought to be particularly harmful to infant health.¹³ The

¹² These data can be accessed at http://www.ehib.org/maps/servlet/MetadataTool?res=CA_wq_measures_1999_2012.xml format=classic.

¹³ The effects of nitrate on infant health have been debated in the medical literature, with some claiming a lack of evidence to support a causal relationship and others demonstrating a relationship between nitrate exposure in utero and low birth weight (Manassaram, Backer, and Moll 2005). Work on arsenic has shown a relationship between arsenic and low birth weight (Rahman et al. 2009).

CDPH produced a fact sheet in 2012 on nitrate in drinking water, stating that nitrate consumption above the health threshold is potentially dangerous for infants and pregnant women. The City of Fresno regularly detects nitrate at levels of concern and in their 2001 Water Quality Report advised pregnant women to drink bottled water.¹⁴ Long-term arsenic exposure in adults can cause cancer of the bladder, lungs, skin, kidneys, nasal passages, liver, and prostate.¹⁵

In addition to the health concerns associated with these two chemicals, they provide examples of two different contaminant-level regulatory regimes. The MCL for nitrate was established at 10 mg/L in 1977 by the Federal EPA and adopted by California in the same year. The MCL for nitrate has not been revised since 1977 and presumably water systems have had many years to adapt to the standard and lower contaminant levels by developing appropriate treatment technology. The study of nitrate provides an example of the response by systems to violations in the context of a long established regulation. In contrast, the MCL for arsenic was set at 50 µg/L in 1977 at both the Federal EPA and state level but was revised to 10 µg/L in 2006 by the Federal EPA, with final implementation by CA in 2008. As this revision occurred fairly recently, the arsenic analysis addresses the response of contaminant levels to violation status overall, pre- and post-revision, as well as the response to the revision itself. Additionally, nitrate MCL revisions require Tier 1 notification (within 24 h of violation), while arsenic MCL violations require notification within 30 days of violation. Thus, there is also variation in the immediacy of public scrutiny after an MCL violation under each contaminant.

Table 1 illustrates the trends over time in sampled systems, violations (system/quarter), and the mean concentration for both of the contaminants of interest. Beginning with the statistics on nitrates, Table 1 shows that the number of violations has fluctuated over time with a slight upward trend over the sample period. However, the mean contaminant level across in violation systems has remained fairly constant over time. Systems without violations over the sample period also have low, constant contaminant levels. Trends in nitrate contrast with the results on arsenic. Over the sample period, the number of violations for arsenic has increased dramatically since 2006 when the MCL standard was revised at the Federal level, and again in 2008 when CA fully implemented the MCL revision. The mean concentration across violating systems appears to have decreased during the sample period; however, this is somewhat misleading due to the revision of the violation rule in 2006. Following the results on nitrate, the mean concentration on nonviolating systems is stable over time.

¹⁴ As discussed in the Natural Resources Defense Council Report on Fresno's drinking water, see <http://www.nrdc.org/water/drinking/uscities/pdf/fresno.pdf>.

¹⁵ See <http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/Basic-Information.cfm>.

Table 1: Trends in systems, violations, and mean concentrations, 2000–2012.

Year	Nitrates				Arsenic			
	Number of systems	Number of violations quarter/system	Mean concentration in violation systems	Mean concentration no violation systems	Number of systems	Number of violations quarter/system	Mean concentration in violation systems	Mean concentration no violation systems
2000	765	0	–	1.88	295	0	–	1.97
2001	765	4	21.81	1.84	295	0	–	1.76
2002	765	11	8.97	2.05	295	3	74.33	2.32
2003	765	23	9.79	2.04	295	0	–	2.71
2004	765	16	11.34	2.07	295	4	21.15	2.17
2005	765	14	12.00	2.08	295	1	18	2.74
2006	765	17	10.68	2.05	295	18*	42.35	1.89
2007	765	29	8.70	2.14	295	23	38.10	1.85
2008	765	17	8.53	2.18	295	28	26.41	1.97
2009	765	21	10.17	2.13	295	18	22.73	2.26
2010	765	23	9.79	2.11	295	13	28.44	1.86
2011	765	30	10.92	2.05	295	12	25.46	1.69
2012	765	12	12.28	2.15	295	6	40.51	1.53

Note: This table shows trends in water systems in the balanced panel for both nitrate and arsenic over the study period.

*The arsenic standard revision began in 2006 with the federal mandate to revise the MCL standard from 50 to 10 µg/L. The arsenic standard revision transition period ended when California formally adopted the standard in 2008.

To study pollution trends over time it is important to include only systems sampled over the entire study period. Particularly for arsenic, the number of systems with samples reported jumped dramatically after the MCL revision. Without balancing the panel to include only systems sampled before and after revision, it is difficult to understand how contaminant levels changed as a result of the revision. To understand the trend over time in contaminant levels and evaluate the effect of revision on arsenic levels, I create a panel of the 295 systems with at least one sample in every year from 2002 to 2012. I construct a similar panel for nitrate to examine the change in average nitrate levels over time, with 765 systems with at least one sample in every year from 2002 to 2012.

From Figures 1 and 2, we can see the distribution across counties of violations for both nitrates and arsenic. Nitrate violations are limited to 18 counties

Figure 1: Fraction of county systems ever in violation of nitrate.
Note: This figure shows the fraction of systems in a given county that are ever in violation of the nitrate standard.

Figure 2: Fraction of county systems ever in violation of arsenic.
Note: This figure shows the fraction of systems in a given county that are ever in violation of the arsenic standard.

with 75 water systems affected, or in violation at least once, across counties (or 2.6% of systems across counties). Arsenic is much more widespread, covering 29 counties and affecting 151 water systems (or 5.1% of systems across counties). As the largest source of nitrate pollution is agriculture, the limited distribution of nitrate is not surprising.

4.4 Methodology

I will follow the methodology presented in Hanna and Oliva (2004) as the context is very similar. To estimate the effect of violations on contaminant levels, I use an event study. The event study framework is appropriate in this context as the treatment

(violation status) occurs at different times for each water system. Because the timing of treatment varies across water systems, I can control for time fixed effects as well as time-invariant unobservables through system-level fixed effects.

Theoretically, violation status will affect pollutant levels, as once a violation is triggered the system is subject to intense public and regulatory scrutiny until contaminant levels are brought below the MCL. Following the conceptual framework, if systems wish to avoid the costs associated with continued public scrutiny, we would expect to see a decrease in pollutant levels after a violation. With regulatory interventions such as inspections, systems may be selected for inspection because they have higher emissions, introducing selection bias. Because violation status is triggered by samples above the MCL and not regulatory targeting, this analysis avoids the confounding issue of system selection but introduces a concern about mean reversion. An event study is useful in that the coefficients on the pre-violation dummies can be used to determine if contaminant levels spiked immediately before violation and to address whether any post-violation decrease in contaminant levels is greater than that expected if contaminant levels simply reverted to the mean.

I estimate the following equation for nitrate and arsenic:

$$\text{mean concentration}_{iyq} = \sigma + \sum_{k=-7}^7 \beta_k D_{t-k,iyq} + \gamma_i + \delta_y + \alpha_q + \varepsilon_{iyq} \quad [1]$$

where $\text{mean concentration}_{iyq}$ is the mean concentration of arsenic or nitrate in system i in year y and quarter q and includes system, γ_i , year δ_y and quarter α_q fixed effects. $D_{t-k,iyq}$ represents the leads and lags from seven quarters before the violation to seven quarters after the violation for nitrate and six quarters before and after for arsenic. Standard errors are clustered at the water system level to account for within-water system correlation. The sample is restricted to a balanced panel in which I observe contaminant levels for each of the seven quarters before and after violation (or six quarters before and after violation for arsenic). Because the dataset is a balanced panel, I can control for time-invariant unobserved system-level determinants of contaminant levels through the water system fixed effects. Additionally, through year fixed effects, I can control for any unobserved shocks that affect contaminant levels across all systems in a given year. To account for systems with multiple violations in sequence, I construct a series of concurrent dummies, allowing a given period to take multiple lead or lag values. Thus, $\sum_{k=-7}^7 D_{t-k,iyq}$ may be greater than 1. The omitted category is the quarter/year of violation, or quarter/year 0.

Specification [1] is useful to evaluate the trend in contaminant levels prior to violation, as we can observe pre-violation spikes in contaminant levels, and also

to evaluate whether a decline in contaminant levels post-violation is due to mean reversion. To estimate the treatment effect, I use a grouped specification:

$$\text{mean concentration}_{iyq} = \sigma + \beta_{-7to7}D_{-7to7} + \beta_{0to7}D_{0to7} + \gamma_i + \delta_y + \alpha_q + \varepsilon_{iyq} \quad [2]$$

where β_{0to7} is the coefficient of interest, giving the change in contaminant levels in the seven quarters following a violation.

Violations may not have a significant effect on contaminant levels if violations are persistent over time. If systems in violation tend to remain in violation, contaminant levels do not respond to violation status. To explore persistence in violation status, I estimate a linear probability model:

$$1(\text{violation})_{iyq} = \sigma + \sum_{k=-4}^0 \beta_k 1(\text{violation})_{iyq-k} + \gamma_i + \delta_y + \alpha_q + \varepsilon_{iyq} \quad [3]$$

where the probability of violation this quarter/year, $1(\text{violation})_{iyq}$, is a function of violation status in the previous four quarters, system, γ_i , year δ_y and quarter α_q fixed effects.

5 Results

I will first address the trends in contaminant levels for both nitrate and arsenic, and the effect of the arsenic standard revision. Figure 3 shows the average yearly

Figure 3: Nitrate yearly average contaminant levels, 2002–2012.

Note: This figure shows the average yearly nitrate contaminant levels over time. The sample is systems with at least one sample per year in every year from 2002 to 2012. There are 765 systems in this sample.

Figure 4: Arsenic yearly average contaminant levels, 2002–2012.

Note: This figure shows the average yearly arsenic contaminant levels over time. The sample is systems with at least one sample per year in every year from 2002 to 2012. There are 295 systems in this sample. The vertical line at 2006 denotes the beginning of the revision of the standard and the vertical line at 2008 denotes the period when the new standard was fully adopted.

nitrate levels across the 765 systems with at least one sample per year over 2002–2012. This figure indicates that nitrate contaminant levels have increased over the study period, with a distinct jump in 2007. There is no documented regulatory change in 2007 and it is unclear what might drive this jump aside from perhaps an abrupt increase in agricultural nitrate use.¹⁶

Figure 4 shows the average yearly arsenic contaminant levels over time, over the 295 systems with at least one sample in every year from 2002 to 2012. The first vertical line indicates the initial arsenic revision (2006) and the second when the revision was fully incorporated (2008). From this figure, we can evaluate the effect of the revision on contaminant levels. A linear prediction is shown for the pre-, during, and post-revision periods. While there is no clear break at revision, the trend in arsenic levels changes distinctly after revision is completely incorporated, with a steep drop in arsenic contaminant levels in the 4 years after revision. To exploit the quarterly variation in the data, I construct the quarterly average arsenic contaminant levels from 2002 to 2012. Although this allows for within-year variation, the sample of systems observed over all quarters from 2002 to 2012 is very small, with only 18 systems. These systems are spread across six counties: Alameda, Los Angeles, Mendocino, San Diego, Santa Clara, and Solano County. They range in

¹⁶ As documented by the USDA, agricultural commodity prices spiked between 2006 and 2008, rising by nearly 60%. Source: http://www.ers.usda.gov/media/218027/wrs0801_1_.pdf.

Figure 5: Arsenic quarterly average contaminant levels, 2002–2012.

Note: This figure shows the average quarterly arsenic contaminant levels over time. The sample is systems with at least one sample per quarter in every quarter from 2002 to 2012. There are 18 systems in this sample. The vertical line at quarter 1, 2006 denotes the beginning of the revision of the standard and the vertical line at quarter 4, 2008 denotes the period when the new standard was fully adopted. The coefficient from a regression of mean quarterly contaminant levels on a dummy for the post-implementation period (i.e. after fourth quarter 2008) and a time trend (year/quarter) is -1.333 with a robust standard error of 0.150 .

size of population served, from those serving 40 people to those serving almost 1 million. Thus, despite the small sample size, these 18 systems provide a representative sample of California's PWSs covering both large and small systems across counties of varying sizes.¹⁷ The results from this sample are illuminating. Figure 5 shows a clear discontinuity at the year when the standard was fully adopted, suggesting that revision caused a significant decrease in contaminant levels. The coefficient from a regression of mean quarterly contaminant levels on a dummy for the post-implementation period and a time trend is -1.333 with a robust standard error of 0.150 , indicating that the effect of the revision on contaminant levels was negative and statistically significant.

Moving to the results from the event study, the coefficients from Specification [1] are graphed in Figures 6 and 7. Beginning with nitrate, Figure 6 shows that nitrate

¹⁷ While these systems provide broad coverage in terms of size and county location, the results indicate a more dramatic discontinuity at revision than the year-level panel. Thus, there may be something unobservably different about these systems. The full year-level panel appears to lag the drop in contaminant levels from these systems, although contaminant levels in the year-level sample do fall dramatically by 2010.

Figure 6: Nitrate event study.
Note: This figure shows the result of an event study to study the effect of violation on nitrate concentrations. This includes seven quarters prior to violation and seven quarters post-violation. The analysis is centered at year 0; all coefficients are relative to the year/quarter of violation and 95% confidence intervals are shown. The analysis includes system, quarter, and year fixed effects and a year trend. The analysis is from a balanced panel with 42,765 observations, including violating systems and control systems.

Figure 7: Arsenic event study.
Note: This figure shows the result of an event study to study the effect of violation on arsenic concentrations. This includes six quarters prior to violation and six quarters post-violation. The analysis is centered at year 0; all coefficients are relative to the year/quarter of violation and 95% confidence intervals are shown. The analysis includes system, quarter, and year fixed effects and a year trend. The analysis is from a balanced panel with 23,667 observations, including violating systems and control systems.

levels remain relatively flat prior to a violation period, spike post-violation, and remain slightly higher than the pre-period. From the event study, there is no evidence of mean reversion, as pollution levels do not spike prior to violation. To understand the magnitude and significance of this effect, I estimate Specification [2]. The results from this specification are shown in Table 2. Following the increase we observe in Figure 6, we see in Table 2 Column 1 that contaminant levels actually significantly increase when averaged over the seven quarters following a violation.

Table 2: Event study, contaminant levels and violation status.

	(1) Nitrate	(1) Arsenic
Violation in the current quarter or any of the seven previous quarters	0.8976** (0.3626)	
Violation in the current quarter or any of the six previous quarters		1.3709 (1.1372)
Year and quarter fixed effects	×	×
Water system fixed effects	×	×
Year trend	×	×
Mean contaminant level	2.2193	3.9293

Note: This table shows the results of regressing contaminant levels on a dummy for any of the seven quarters before and after a violation (six quarters before and after a violation for arsenic) and a dummy for the seven quarters after violation and the year of violation (6 years after and quarter of violation for arsenic). The balanced panel has 42,765 observations for nitrate and 23,667 for arsenic. Standard errors clustered at the system level are shown in parentheses. Significance is given by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. × indicate that the column includes the listed.

From Figure 7, violations appear to have little effect on contaminant levels for arsenic. There does appear to be a small dip after violation, relative to one quarter before violation where we see a spike in contaminant levels. However, this dip is very small and evaluating the entire post-violation trend, contaminant levels do not appear to change significantly. To estimate this change in contaminant levels over the six quarters following a violation, I estimate Specification [2]. As we see in Table 2, arsenic violations do not have a significant effect on contaminant levels.¹⁸ One concern is that systems with many

¹⁸ Very few systems are in violation before the MCL revision; two systems in the dataset have one or more violations in the pre-MCL period with samples for four leads and lags surrounding violation. Although the results shown here include violations from both the pre- and post-period, they are likely driven by violations in the post-MCL period. Event studies for the pre- and post-period are available upon request.

violations over the sample period react differently than those with very few violations. I also limit the analysis over the entire sample period to only systems with fewer than six quarters in violation and find no significant difference in the effect of violations on contaminant levels in these systems.¹⁹

To explore the persistence of violations over time, I estimate Specification [3]. The results of this specification are shown in Table 3. These results suggest that a violation one quarter prior has a positive, statistically significant effect on the probability of being in violation this quarter. For nitrates, this effect is positive and significant for a violation two quarters prior, indicating a strong persistence of violation status. The persistence of violations supports the results of the event study; systems with an MCL violation do not lower contaminant levels to return to compliance in the periods following violation.

Table 3: Prior violations and current probability of violation.

	(1) Arsenic	(1) Nitrate
In violation one quarter prior	0.6181*** (0.0351)	0.3928*** (0.0564)
In violation two quarters prior	-0.0152 (0.0323)	0.1080*** (0.0409)
In violation three quarters prior	-0.0261 (0.0305)	0.0013 (0.0352)
In violation four quarters prior	-0.0044 (0.0327)	0.0509 (0.0414)
Quarter and year fixed effects	×	×
Water system fixed effects	×	×
Year trend	×	×

Note: This table shows the results of regressing violation status in period t on violation status in the prior four periods to assess the persistence of violations. Standard errors are clustered at the water system level and are shown in parentheses. There are 6,160 observations for arsenic and 17,234 for nitrate. Significance is denoted by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. × indicate that the column includes the listed.

These results suggest that violations do not trigger a decrease in contaminant levels post-violation for either nitrates or arsenic. Additionally, I find that the arsenic revision appears to have triggered lower contaminant levels. The result on the arsenic revision suggests a deterrence effect; that is, that systems wish to avoid being in violation, under the scrutiny of regulators and the public. After the MCL revision, when the threshold for triggering a violation is lower, systems

¹⁹ Results are available upon request.

lower their contaminant levels in response to avoid violations under the new rule. This supports the previous work of Benneer and Olmstead (2008), suggesting that public notification encourages systems to remain in compliance as the consequence of violation status is increased focus from the public and regulatory authorities. However, my results suggest that the increased scrutiny following violation is ineffective at encouraging systems to return to compliance and decrease contaminant levels. The results from the event study on both nitrates and arsenic support this. Even systems with nitrate violations, that are subject to Tier 1 notifications, do not react by decreasing contaminant levels.

It is possible that systems lack the ability to address nitrate violations, and the observed significant positive coefficient on the post-violation period is due to an exogenous increase in nitrate concentrations due to factors outside of the system's control and treatment abilities. It is difficult for systems to change their treatment technologies in the short run; however, they do have the ability to mitigate contaminant levels by blending in uncontaminated water or closing off wells that are of particular concern. Their actual ability to implement these solutions in any given period is unobserved and so this case cannot be ruled out entirely.

While it is plausible that systems cannot immediately return to compliance if compliance is very costly, the event study considers seven (or six for arsenic) quarters following violation which allows systems almost 2 years to decrease contaminant levels. I do not find a decrease even seven quarters following a violation. Further evidence on this is given by the results of the linear probability model as systems in violation last quarter are more likely to be in violation this quarter, suggesting that violating systems remain in violation despite the necessity of repeated public notification and disclosure requirements of the CCRs. These findings suggest that while public scrutiny may deter systems from violating, once they go into violation the Public Notification Rule is not effective at encouraging them to return to compliance.

6 Conclusion

This work contributes the first study of the response of water system contaminant levels to violations. I use an event study to study the effect of violations on two important contaminants, arsenic and nitrate, that are both widespread and a threat to human health. Additionally, these contaminants allow for the examination of two different contaminant-level regulatory regimes. The violation rule for nitrate has not been revised since the late 1970s and thus nitrate provides an example of a long established regulatory rule. In contrast, the MCL for arsenic was revised during the study period. Arsenic affords the opportunity to study the

effect of violations before and after revision and provides an example of a contaminant under a recently revised regulatory rule. Additionally, the revision of the arsenic standard provides an opportunity to study the deterrence effect of water systems attempting to avoid violations. Because the main mechanism for encouraging systems to return to compliance is public disclosure, this study also contributes to the understanding of the effectiveness of public scrutiny at incentivizing systems to remedy violations.

This work finds, through an event study, that violations of the arsenic and nitrate MCLs do not trigger a decrease in contaminant levels. While previous work has found that public disclosure deters SDWA violations, public scrutiny does not seem to be an effective pressure on systems that are in violation to remedy their noncompliance and decrease contaminant levels. For nitrates, the rule has been in place for decades, yet MCL violations continue. Additionally, this analysis suggests that violation status is somewhat persistent. While the immediate prior period violation status is a predictor of current period violation status, this effect does not persist further out than two quarters from a violation.

However, the study of the arsenic revision provides some evidence that water systems avoid triggering violations, as there is a discontinuity in contaminant levels after revision. The examination of arsenic and nitrates suggests that public review may deter systems from violating, but post-violation the threat of continued public scrutiny and reporting has little effect on contaminant levels. This paper contributes to the existing work on the effect of public disclosure and scrutiny on compliance with the SDWA.

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